TECHNICAL MEMORANDUM REPORT
M65-1-1

UNITED STATES ARMY

FRANKFORD ARSENAL

STRESS CORROSION TESTS OF SOME WROUGHT Mg-Li BASE ALLOYS

by

J. C. KISZKA

22p
h -1.00
mf -0.50

July 1964

AMCMS Code 5026.11.84202
DA Project 59332007

REPORT M65-1-1

PHILADELPHIA, PA. 19137

DDC AVAILABILITY NOTICE

Qualified requesters may obtain copies of this report from Defense Documentation Center, Cameron Station, Alexandria, Va. 22314

DISPOSITION INSTRUCTIONS

Destroy this report when it is no longer needed. Do not return it to the originator.

Research and Development Directorate
FRANKFORD ARSENAL
Philadelphia, Pa. 19137

MEMORANDUM REPORT M65-1-1
July 1964
AMCMS Code 5026.11.84202
DA Project 59332007

STRESS CORROSION TESTS OF SOME WROUGHT Mg-Li BASE ALLOYS

Prepared by: John C Kiszka
JOHN C. KISZKA
Metallurgist

Reviewed by: H Markus
H. MARKUS
Director
Metallurgy Research Laboratory

Approved by: A L Jamieson
A. L. JAMIESON
Deputy Director
Pitman-Dunn Institute for Research

ABSTRACT

Seven experimental wrought Mg-Li base alloys (Mg-14Li with various additions of Al, Zn, Ag, and/or Si) were tested for stress corrosion susceptibility in humid air, following mechanical and thermal processing to approximate conditions in the heat-affected zone of a weld. Stress levels during exposure were uncertain because of creep effects.

Rapid cooling from 700° F rendered susceptible those alloys containing aluminum, regardless of other alloy content. However, heating for 24 hours at 300° F following such rapid cooling restored their resistance to stress corrosion. Alloys strengthened by additions of zinc, silicon, and/or silver, but with aluminum excluded, did not fail in stress corrosion under the conditions of test used in this study.

TABLE OF CONTENTS

List of Tables

List of Figures

INTRODUCTION

The magnesium-lithium base alloy system has been extensively investigated for possible low density structural alloys. Interest has been centered primarily in those alloys containing 12 or more weight percent of lithium because they have a ductile, body-centered cubic crystal structure which can be strengthened by additions of aluminum or zinc, and other elements. During evaluation of two-inch thick armor plate made of one such alloy (Mg-14Li-1.5AL), delayed cracking occurred in the vicinity of constrained welds. The cracking was attributed to stress corrosion susceptibility in the ambient atmosphere. Busk[1*] had previously noted that the magnesium-lithium base alloys were susceptible to stress corrosion in an atmosphere of humid air. However, the effects of alloy content or thermal treatments had not been determined.

Recently, interest in the magnesium-lithium base alloy system has been stimulated because of the potential value of its high stiffness-to-density ratio for structures in space vehicles. In recent work at this arsenal, magnesium-lithium base alloys with improved stable strength levels have been developed.[2,3] These alloys contain silicon, zinc, and silver as strengtheners. In view of the possible stress corrosion effects of such added elements, exploratory tests of stress corrosion susceptibility of several typical alloys were conducted.

EXPERIMENTAL WORK

The alloys were prepared by melting under argon, without flux, and were cast into iron molds, also under argon cover. (The details of the method of preparation are described in an article[4] by A. Saia in the August 1962 issue of Foundry.) They were then processed by hot working and rolling to finished thickness. The specimens were taken with the length in the rolling direction. All the specimens were oil-quenched from 700° F, followed by aging and stressing under conditions approximating those that might occur in the heat-affected zone of a weld. Thermally stabilized specimens were also tested to determine the effectiveness of such a treatment in reducing stress corrosion susceptibility after rapid cooling. The nominal compositions of the alloys and the processing conditions used are given in Tables I and II. The codes in these tables for each alloy and thermal treatment are those used in the discussion and tabulation of the results.

The strength level reached by each specimen as a result of the thermal treatment applied was estimated from a hardness determination

*See REFERENCES.

TABLE I. List of Alloys

Code	Nominal Composition (Wt %) Mg	Li	Al	Zn	Ag	Si
1	84.5	14.0	1.5			
2	84.0	14.0	1.5			0.5
3	80.5	14.0	1.0	1.0	3.0	0.5
4	80.0	14.0		1.0	3.0	2.0
5	83.0	14.0		3.0		
6	83.0	14.0				3.0
7	80.0	14.0			3.0	3.0

TABLE II. Mechanical and Thermal Treatments

Code	Treatment
A	Oil quench, 700° to 200° F; air cool; age at room temperature 100 hours.
B	Oil quench, 700° to 200° F; stabilize at 300° F, 48 hours.
C	Oil quench, 700° to 200° F; roll 30 percent at 200° F; stabilize at 300° F, 48 hours.
D	Oil quench, 700° F to room temperature; age at room temperature 24 hours.
E	Oil quench, 700° F to room temperature; age at room temperature 2 hours.

and a previously prepared plot of strength vs hardness. Figure 1 shows the plot of hardness vs tensile strength used for this purpose. Several specimens below the range of strengths covered by this correlation were estimated by extrapolation in order to conserve material. The estimated strength values shown in Table III were applied in the formula given below to determine the deflection needed for the intended stress level. Values of strength and hardness obtained from specimens that did not fail in stress corrosion were added to the plot in order to show that the strength-hardness relation in these specimens had not been affected by the exposure.

Flat beam specimens were stressed by bending and exposed in a setup which is shown schematically in Figure 2. The deflection to produce the intended stress level was determined for each specimen from the relation[5]

$$d = \frac{2\ell^2\sigma}{\pi^2 Et}$$

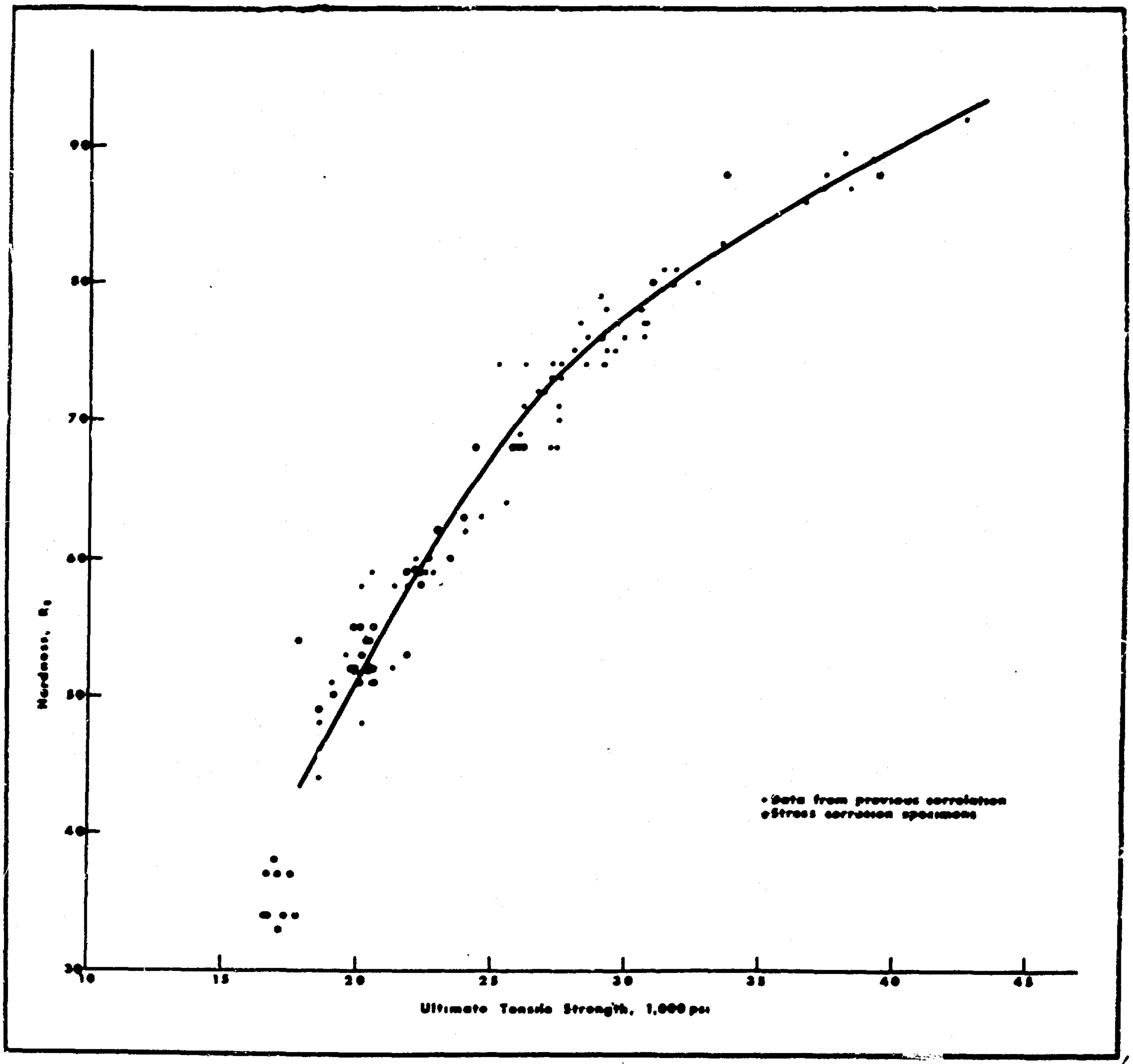


Figure 1. Rockwell E Hardness vs Ultimate Tensile Strength for various Mg-Li Base Alloys

where d = the deflection;

ℓ = the length of the specimen;

E = the modulus of elasticity, taken as 6×10^6 psi;

t = the thickness of the specimen;

σ = the intended stress level.

TABLE III. Average Estimated Tensile Strengths Obtained from Strength Hardness Correlation

Code		Hardness	Est Ultimate Tensile Strength
Alloy	Temper	R_E	(psi)
1	A	84	35,100
1	B	50	19,200
1	C	59	22,500
1	D	59	22,500
1	E	78	30,300
2	A	89	39,200
2	B	52	19,800
2	C	63	23,500
2	E	79	30,700
3	A	92	43,000
3	B	59	22,500
3	C	68	25,800
3	D	69	26,100
3	E	60	22,800
4	A	85	36,000
4	B	60	22,800
4	C	68	25,800
4	E	64	24,000
5	D	50	19,500
5	E	49	19,200
6	D	36	15,700
6	E	38	16,200
7	D	52	20,000
7	E	52	20,000

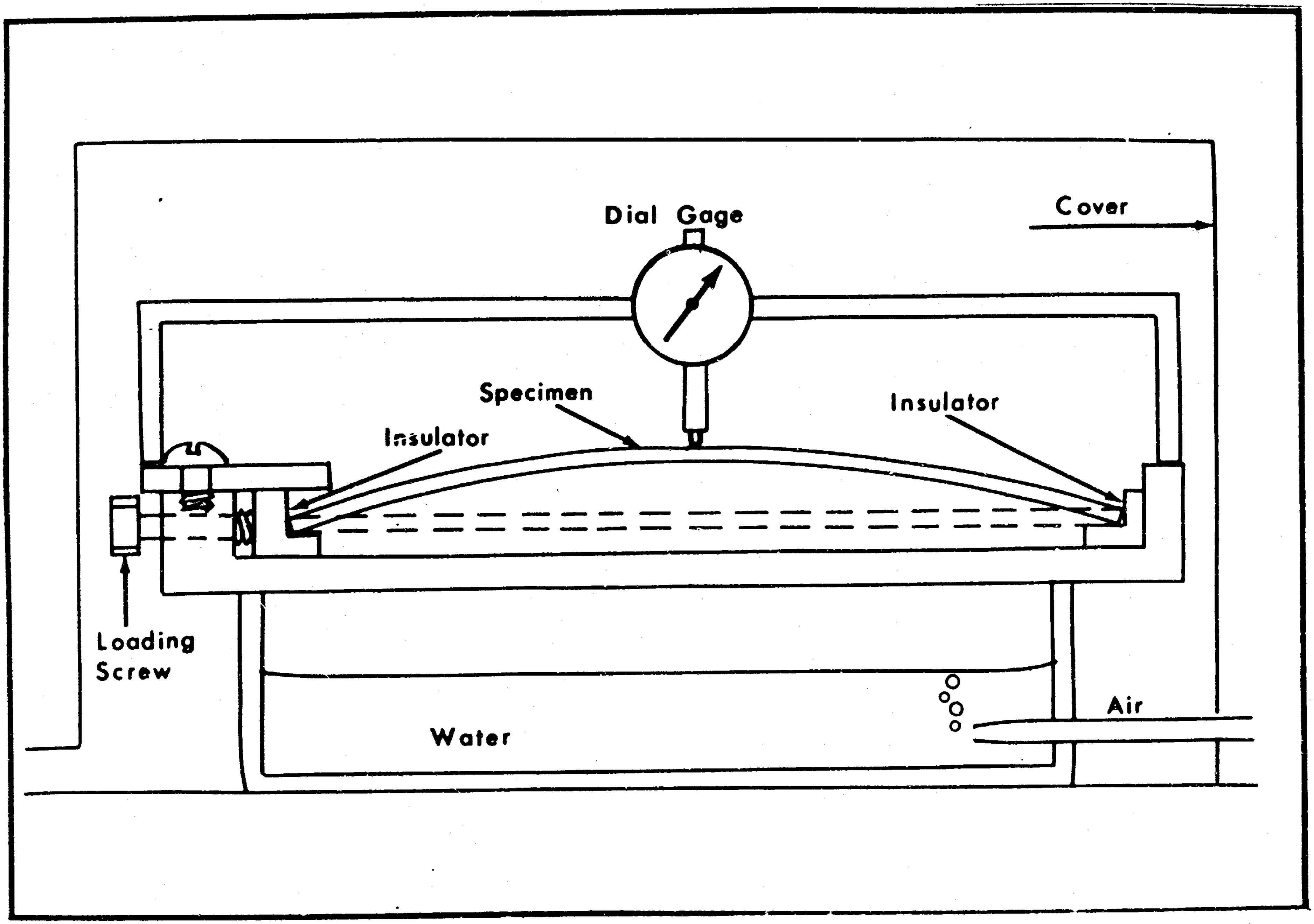


Figure 2. Setup Used for Stress and Exposure Tests

The alloys listed in Table I were exposed in two groups. The first group of specimens (alloys 1, 2, 3, and 4) was exposed at a stress of 0.7 times the ultimate strength. The second group (alloys 1, 3, 5, and 6) was exposed at the yield stress by applying a deflection calculated for a stress level 1.1 times the ultimate strength in the outer fiber, where plastic deformation maintains the stress at the yield level.

An exposure environment of humid air at ambient temperature was maintained by placing the fixture over a shallow pan of water through which a stream of air (approximately two cu ft/hr) was bubbled. A plastic cover was placed over the whole arrangement to retain the humidity. The temperature within this enclosure varied between 80° to 90° F, and the relative humidity varied from 85 to 100 percent.

RESULTS AND DISCUSSION

The alloy, temper, and stress levels vs time to break for each specimen are shown in Figure 3. Specimens of several alloys and tempers were exposed unstressed, to indicate the effect of normal corrosion. Full length, flat, tensile specimens were prepared from unbroken stress corrosion specimens after exposure was terminated. Tensile properties obtained are given in Table IV. Typical microstructures observed in the vicinity of crack formation are presented in Figure 4.

Results obtained in these studies show that stress corrosion susceptibility in Mg-Li base alloys is associated with aluminum content and with the unstable condition that results from rapid cooling of these alloys from high temperatures. The alloys with no significant aluminum content withstood the stress corrosion exposure without failure in all conditions tested, while the alloys containing aluminum failed in all cases except those where the specimens had been overaged by a thermal treatment.

Alloy 4, one of the age-hardenable alloys strengthened by additions of zinc, silicon, and silver, was stressed and exposed in two tempers - A and E. The A temper produced the highest strength in this alloy, and the E temper was the one in which [illegible] earliest stress corrosion failure was observed. The ability of alloy 4 to withstand the applied stresses in these conditions suggests that it would be less prone to failures in constrained welds than the alloys hardened by aluminum.

The silver and silicon contents in the various alloys did not correlate with stress corrosion behavior.

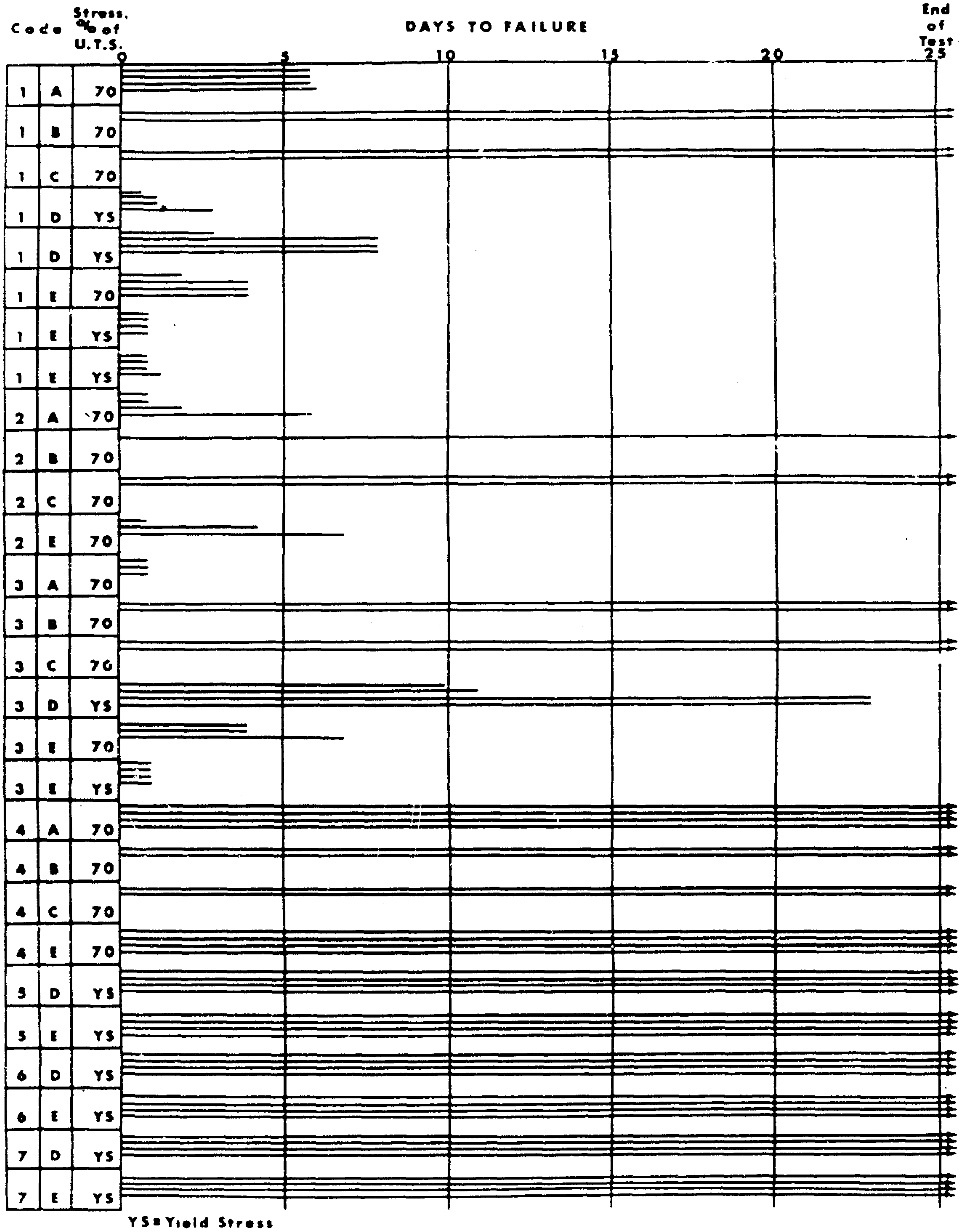


Figure 3. Results of Stress Corrosion Tests in Humid Air for seven Mg-Li Base Alloys

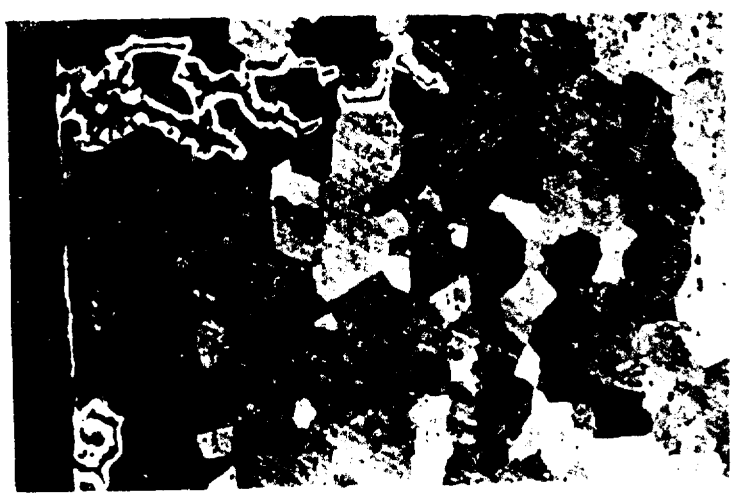
TABLE IV. Mechanical Properties after Exposure

Code		Strength (psi)		%	
Alloy	Temper	Ultimate Tensile	Yield (0.2% Offset)	Elongation in 2 in.	Hardness R_E
1	B	19,100	17,300	40	50
1	B	18,600	16,900	38	49
1	C	21,800	18,800	38	59
1	C	22,300	19,900	30	59
1	D*	29,700	28,800	9	77
1	E*	29,000	28,300	5	76
2	B	19,900	17,200	31	52
2	C	23,000	21,100	35	62
2	C	23,900	20,800	33	63
3	B	22,600	19,800	29	60
3	B	22,300	19,900	32	58
3	C	26,100	23,600	29	68
3	C	21,400	22,800	26	68
3	D*	39,400	-	2	88
3	E*	33,700	-	1	88
4	A	30,900	30,100	25	80
4	A	31,600	30,800	22	80
4	B	23,400	21,300	33	60
4	B	22,200	20,000	40	59
4	C	25,700	23,900	24	68
4	C	25,900	23,800	27	68
5	D	19,900	16,400	30	55
5	D	20,100	16,500	31	55
5	D	17,800	15,200	30	54
5	D	20,600	16,800	28	55
5	D*	19,800	16,100	28	52
5	E	20,400	16,600	25	54
5	E	20,200	16,100	27	53
5	E	20,400	16,300	29	52
5	E	20,400	15,900	26	52
5	E*	20,400	16,300	25	54
6	D	17,100	12,600	27	33
6	D	17,800	13,300	26	34
6	D	17,300	13,000	30	34
6	D*	17,600	13,500	27	37
6	E	16,700	12,000	33	37
6	E	17,000	13,400	44	38
6	E	16,700	12,600	36	34
6	E	16,700	12,700	36	34
6	E*	17,100	11,900	31	37
7	D	20,600	16,100	26	52
7	D	20,100	15,800	25	51
7	D	20,600	16,600	26	51
7	D	21,800	18,700	26	53
7	D*	19,800	15,900	26	52

*Exposed unstressed.

No. 1 - Mg-14Li-1.5Al 100X

No. 3 - Mg-14Li-3Ag-1Al-1Zn-.5Si 1000X



No. 3 - Mg-14Li-3Ag-1Al-1Zn-.5Si 100X

Figure 4. Stress Corrosion Cracking in two Mg-Li Base Alloys

The magnesium-lithium base alloys are subject to creep at room temperature, and loading for stress corrosion testing is uncertain because of relaxation of the applied stress by creep. Simple trials of loading and unloading in the stress corrosion fixtures showed that bending stresses below yield strength, sustained for one hour, produced a substantial permanent set in all the alloys tested. Specimens in the B and C tempers, none of which failed in stress corrosion, were checked for degree of permanent set at the termination of the test. This permanent set was measured as the dial gage deflection remaining in each specimen upon removal of the load (fig. 2).

Since stress is proportional to deflection in this system, the stress remaining prior to unloading may be estimated from the deflection, or permanent set, observed after unloading from the relation

$$\sigma = \frac{\pi^2 Et(d_o - d_r)}{2l^2}$$

where d_o is the deflection originally applied, and d_r is the deflection remaining after unloading. The originally applied stress levels and the corresponding final stress levels are given in Table V. Although these specimens had been stressed in proportion to their tensile strengths, the estimates of the stress levels remaining just before unloading did not follow this proportionality. According to the estimates, the final stress levels of all specimens of the B and C tempers showed a random variation between 8400 and 10,600 psi; whereas the range of ultimate strengths for these materials was 18,500 to 25,800 psi.

Under the conditions of stressing used in this investigation, the applied stress is gradually relieved, approaching a limit determined by the creep stress. From the permanent set observed in this method of loading, it appears that the creep stress is not strongly dependent upon the ultimate tensile strength. Although the permanent set was not measured in every instance, it was observed in all specimens that did not break.

After exposure, the strength and hardness of specimens that did not fail in stress corrosion were about equal to those for corresponding specimens that were exposed unstressed. These values, when added to the plot in Figure 1, showed good agreement with the strength vs hardness trend observed with previous data.

Microstructural examinations were made of failed stress corrosion specimens sectioned across small cracks which had started a short distance from the primary failure. These showed that stress corrosion attack follows grain boundaries. The typical views shown in Figure 4 were obtained from specimens polished under distilled water and coated with immersion oil immediately after etching with a fluoboric acid

solution. The white border seen on each side of the crack is a staining phenomenon that varies with the etching technique; it is not believed significant.

TABLE V. Reduction of Stress Level by Creep

Code		Stress (psi) Originally Applied	At end of Test	
1B		13,400	9,600	
1B		13,000	9,800	
2B		13,900	9,300	
3B		15,700	10,600	
3B		15,300	10,400	
4B		15,800	8,900	
4B		15,500	8,800	
	Avg			9,600
1C		15,500	10,200	
1C		15,500	10,300	
2C		16,300	8,900	
2C		16,600	8,400	
3C		18,100	9,900	
3C		18,100	10,200	
4C		18,100	9,100	
4C		18,100	9,600	
	Avg			9,600

By comparing the stress corrosion results of the D and E temper specimens (fig 3), it may be seen that 24 hours of room temperature aging before stressing had significantly lengthened the time to failure in the alloys containing aluminum. This indicates that early aging changes in the microstructure affect the stress corrosion behavior. According to Frost et al,[6] and Clark,[7] a precipitation hardening reaction is responsible for the strengthening of Mg-Li-Al alloys and the microstructural changes, which involve precipitation of an unstable phase, are submicroscopic. The particles visible in the photomicrographs of alloy number 3 are believed to be silicon compounds. At 100X they are seen to be generally dispersed, and at 1000X they are shown near a crack which continues to follow a grain boundary. Thus, it appears that the visible inclusions of silicon compound do not influence the direction of crack propagation in stress corrosion.

The tensile strength of the various alloy compositions tested shows that substantial strengthening can be achieved by additions

of Zn, Si, and Ag with less stress corrosion sensitivity than is found in alloys containing aluminum as a strengthener. This behavior might be of importance in selecting a Mg-Li base alloy for service where it is impractical to thermally stabilize a structure having constrained welds.

CONCLUSIONS

1. Rapid cooling from 700° F induces stress corrosion susceptibility in humid air environment in Mg-14Li base alloys containing one percent or more of aluminum. Heating for 24 hours at 300° F after the rapid cooling restores the stress corrosion resistance of such alloys in the same environment.

2. Mg-14Li base alloys strengthened by Zn, Si, and/or Ag, but with Al excluded, do not fail in stress corrosion under the conditions of test used in this study.

RECOMMENDATIONS

It is recommended that stress corrosion characteristics of constrained welds of wrought Mg-14Li base alloys strengthened by aluminum addition be compared with those of the best available alloys strengthened by zinc, silicon, and/or silver.

REFERENCES

1. Unpublished work at Dow Chemical Co., circa 1955.

2. A. Saia, R. E. Edelman, H. Markus, "Effect of Silicon on the Mechanical Properties of Magnesium-Lithium Alloys," Proc, World Magnesium Congress, Montreal, Canada, 15-17 Oct 1963.

3. A. Saia, R. E. Edelman, "Effect of Silicon and Zinc on Magnesium-Lithium and Magnesium-Lithium-Silver Alloys," Trans, AFS, April 1964.

4. A. Saia, "Producing Magneium-Lithium Alloy Castings," Foundry, August 1962.

5. H. P. Godard, J. J. Harwood, "Some Remarks on Stress Corrosion Testing," Corrosion, Vol II, No. 2, February 1955.

6. P. D. Frost et al, "Mg-Li Alloys, Preparation, Fabrication, and General Characteristics," Trans, AIME, Vol 185, February 1949.

7. J. B. Clark, "Mechanism and Kinetics of Age Hardening in the Mg-Li Alloy System," Wright Air Development Center, WADC TR 57-405 (ASTIA AD142107), October 1957.